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An Update to a Conformal Ablative Thermal Protection System for Planetary and Human Exploration Missions

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CONTEXT & OBJECTIVE

NASA STMD Game Changing Development Program

What is our Mission?

To focus on transformative space technologies that will lead to advances in space and terrestrial capabilities

Goals

- Develop Game Changing technologies that produce dramatic impacts for NASA's Space Exploration and Science Missions
- Capitalize on opportunities to leverage funding and cost-share from external organizations in technology areas mutually benefiting NASA and the other organizations
- Formulate and implement technology projects that deliver the required performance to stakeholders on schedule and within cost
- Deliver technology knowledge that is used internally for NASA missions as well as externally throughout the aerospace community

Vision

- Focus of the spacecraft design community has been on "heritage" ablative materials for TPS
- Lessons learned during recent builds:
  - Rigid lightweight TPS heritage alternatives (PICA and AVCOAT) have been having significant integration issues
    - Low strain-to-failure of PICA makes direct bonding problematic and requires small tile sizes and gap fillers for large heatshields
    - High touch labor requirements for AVCOAT results in large costs and long schedules, high CTE limits choice of structure materials
- Work was initiated under ETDD and ARMD and continued under STMD/GCDP to develop improved TPS to solve these issues

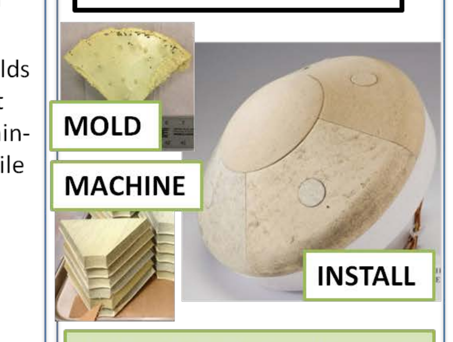
The Vision is to develop and deliver a high strain-to-failure conformal TPS to TRL 5-6 capable of reducing the cost and complexity of protecting an flight aeroshell

Why Conformal?

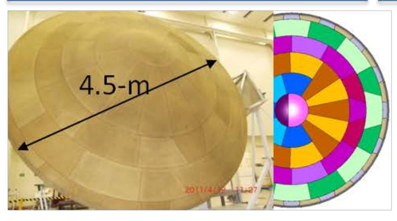
SOA

- Limited number of certified TPS
- PICA tile on a rigid heatshields is limited by small size billet manufacturing and low strain-to-failure resulting in high tile count and gaps with filler design
- Honeycombed concepts (AVCOAT) require extensive touch-labor, large curing ovens, and complicated NDE

Best Conformal Solution

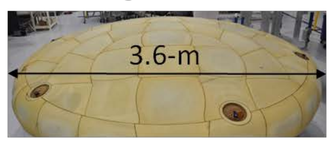


Carbon felt w/ phenolic matrix (C-PICA)



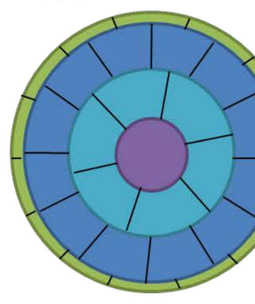
MSL: 113 PICA Tiles

Dragon



Goal

- Deliver TRL5/6 Conformal Ablator



MSL: <35 Conformal tiles (notional for ~1m² part)

Benefits

- Larger TPS part size reduces overall part count and would reduce assembly and integration costs
- High strain to failure TPS allows broader structural design options for rigid aeroshell structure

Continued Systems Engineering Approach to Material Development

Technical Requirements Definition

- *Stakeholder expectations assessed to understand the technical problem and establish the design boundary*
- Defin… antici… ConO…
- Defin…
- Defin… define… functi…
- Defin… bound…

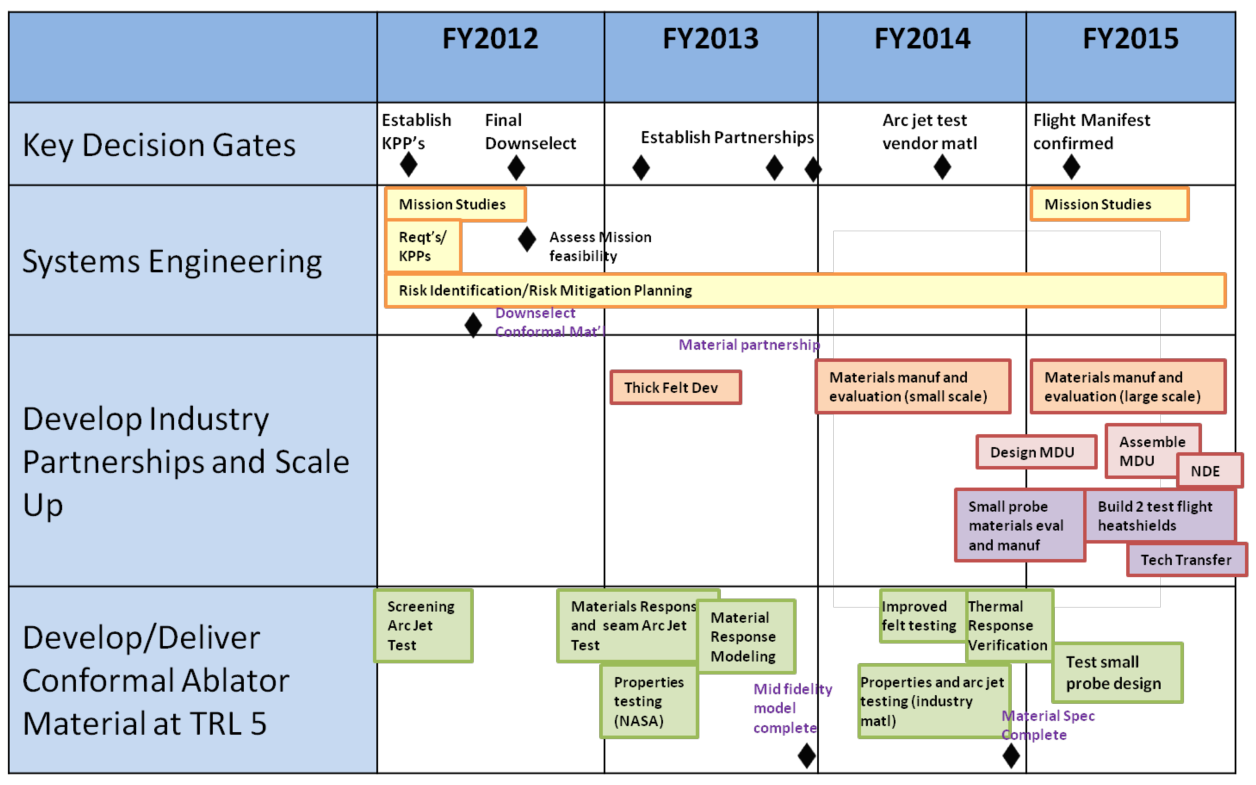
Continuous Risk Management (CRM)

- CRM utilized to provide systematic method for identifying, analyzing, tracking, and communicating risks on a continuous basis
- Embed risk management into normal day-to-day activities to identify and manage risks
- Delegate risk management responsibility to lowest possible organization to mitigate or accept risk
- Dedicate Risk Management Officer to lead risk management

CA-TPS Key Performance Parameters

Conformal Ablators Key Performance Parameters	Category *Definition*	State-of-the-Art Value	TRL 5 Threshold / Goal	Justification
KPP-C1	Survivable for MSL-like and COTS aerothermal environments *Capability required for future Mars and COTS missions*	PICA: >250 W/cm², 0.33 atm, 490 Pa shear	250 W/cm2 / >500 W/cm2	Current goal for Conformal Ablator is to meet MSL-like conditions while satisfying COTS heat shield conditions
KPP-C2	Strain to Failure *Material property that provides an indication of compliance when bonded to an underlying structure*	PICA (<<1%) Avcoat (~1%)	>1% / > 2%	High strain to failure and use of felts for substrates enables factor of >10 reduction in heat shield parts count
KPP-C3	Manufacturing Scalability *Assesses the likelihood that the technology concept will successfully scale to the large sizes required by mission architectures*	20" x 40" PICA max tile size (1m cast monolithic)	1m x 1m / 2m x 2m	Eventual application will require large panels, seams, and close-outs. Heat loads define ablator thickness. The MDU, arcjet testing, and analysis will prove scalability of the ablator to full scale.
KPP-C4	Response Model Fidelity *Ability to reliably and repeatably predict the thermal response of the material to the applied environments*	Mean: bias error 30%, Time to peak error: 30% Recession: 150%	Mean bias error < 40% / 10% Time-to-peak error < 40% / 10% Recession error < 50% / 25%	Working from low to mid to high fidelity models - need the ability to estimate thicknesses for target mission design

CA-TPS Schedule



Testing, Results and Modeling

IHF Stagnation Wedge LHMEL Strain-to-failure Fold

Screening tests (ETDD and ARMD)
Investigate substrates, polymers, solvents, flexible & conformal at 100-500 W/cm2

JSC & HyMETS Stagnation LHMEL Strain-to-failure

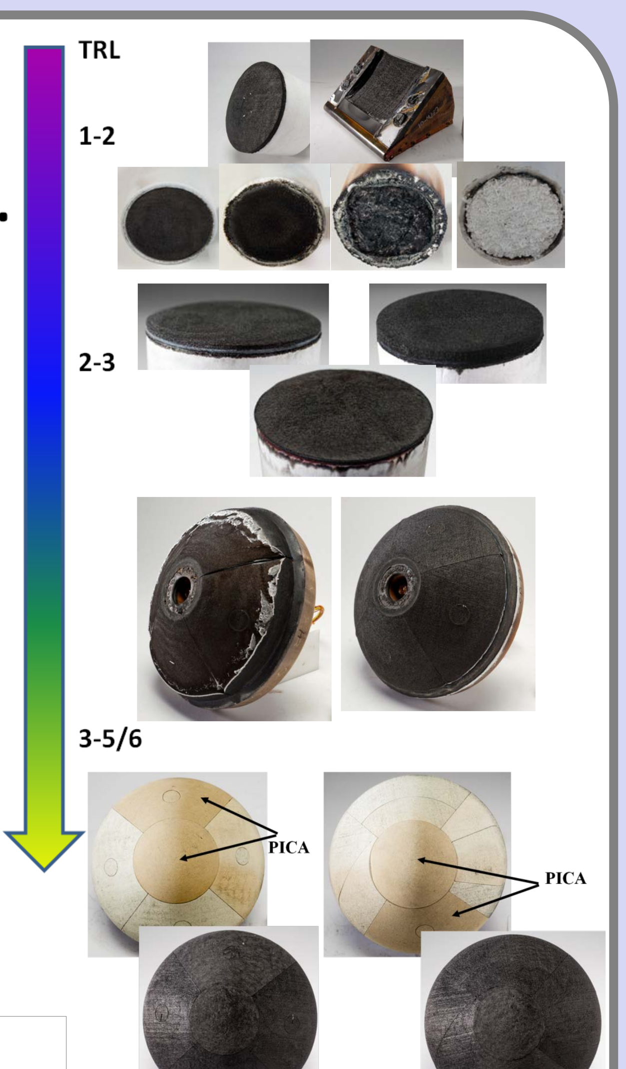
STMD: New requirements: Survive at least 250 W/cm2
Downselection eliminates Silica and PBI substrates
Investigate *carbon* substrates, polymers, solvents, flexible & conformal at 250-500 W/cm2 in stagnation

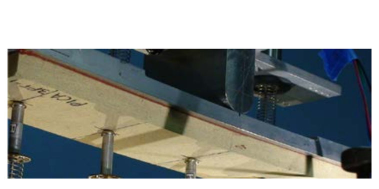
IHF Stagnation SPRITE Strain-to-failure Preliminary props Low Fidelity Model

Downselect to best 2
Test in shear (SPRITE config) at 200 and 400 W/cm2

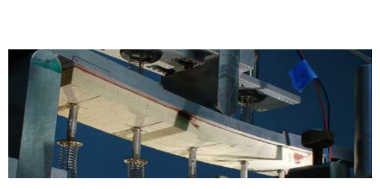
IHF SPRITE (heating and shear) Structural and thermal Mid Fidelity Model Eval Vendor Material

Downselect to Best Conformal PICA
Demonstrate seams
Perform thermal response testing
Demonstrate Scale-up
Develop to TRL 5-6

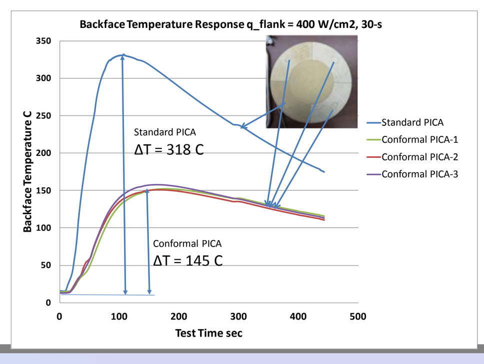


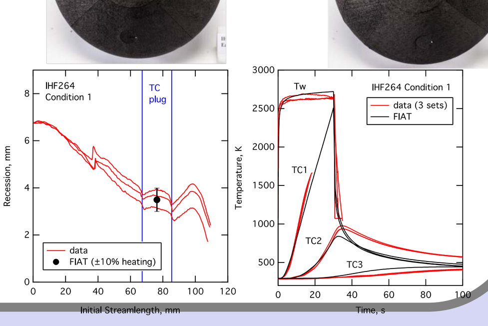


PICA failure
<360 lb, ROC ~135"



C-PICA failure
>1200 lb, ROC ~35"

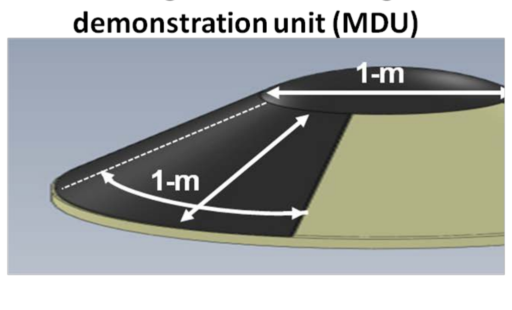




Establish Industry Partnerships

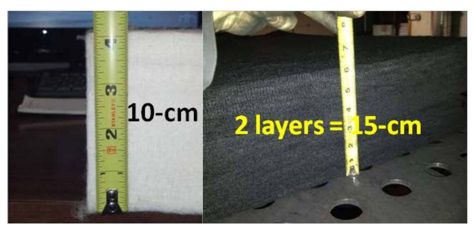
Conformal TPS Manufacturing Scale-Up

- Vendor is required to supply for 1-m or larger MDU:
  - Small-scale samples for matl props and SPRITE followed by large-scale materials for application to the MDU
  - Manufacturing Plan for C-PICA at least 1x1-m scale
  - Non-destructive methodologies necessary to examine variations in the felt structure and the resulting conformal ablator and for bond verification
  - Design support and manufacture of a large manufacturing demonstration unit (MDU)



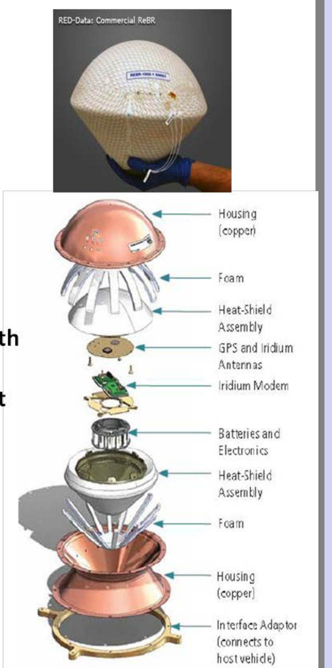
Felt Thickness Scale Up

- State of the art for carbon felt ~1.0-in thick, density 0.8-1.0 g/cm³
- Vendor completed processing of 10-cm thick rayon felt (white goods) at ~525 ounces per square yard (OPSY) – density ~0.23 g/cm³ material manufactured was 2-m wide by 18-m long
- Material carbonized
- Final thicknesses ~7.5-cm, density ~.127g/cm³



Small Probe Vendor

- Technology transfer TPS manufacturing to Small Probe Provider Terminal Velocity Aerospace (TVA) and provide flight test article
  - Perform all work required for Conformal PICA and Conformal Silica-Silicone technology transfer to TVA for small entry probes in FY'15 along with two aeroshell with instrumented TPS
  - Vendor to obtain and deliver flight test data in FY16+ – ReBR/RED flight tests
  - Includes:
    - Plan, build test articles, and perform arc jet testing
    - Vibro/acoustic testing
    - RF transparency testing
    - Manufacture and install TPS and instrumentation for 2 test flight vehicles
    - Technology transfer -- process documentation, training, testing



CONCLUSION & OUTLOOK

***Game Changing*: we have created a high strain-to-failure TPS with a dramatic reduction in complexity and should result in lower cost heatshield manufacturing**

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